Low Spatial Proximity Between Text and Illustrations Improves Children's Comprehension and Attention: An Eye Tracking Study

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Abstract

Learning to read is a critical skill; yet only a small portion of children in the United States are reading at or above grade level. Attention is one crucial process that affects the acquisition of reading skills. The process involves selectively choosing task relevant information and requires monitoring competing demands. Many books for beginning readers include illustrations, but this design choice may require learners to split their attention between multiple sources of information. This study employed eye tracking to examine whether embedding text within illustrations in children's e-books inadvertently induces attentional competition. The results showed that spatially separating illustrations from the text in beginning reader books reduces attentional competition and improves children's reading comprehension. This study shows that changes to the design of books for beginning readers can help promote literacy development in children.

Keywords: attention; reading; reading comprehension; book design; illustrations; eye tracking

Introduction

Learning to read is important in its own right, but this critical skill also supports later learning: challenges in 'learning to read' when children begin formal schooling are often followed by challenges in 'reading to learn' in higher grades (National Association for the Education of Young Children, 1998). There are a number of reasons many children struggle when learning to read, including neurodevelopmental disorders (such as Dyslexia and ADHD), low pre-reading skills (e.g., phonological awareness), and vulnerabilities in general cognitive functioning (e.g., working memory, processing speed) (e.g., Armbruster, Lehr, & Osborn, 2009; Biederman et al., 2004; Dykman, & Ackerman, 1991; Jacobson et al., 2011). In this study, we examine how the design of materials for beginning readers may inadvertently contribute to the challenge of learning to read.

There is a large body of theoretical and empirical work suggesting that the design of educational materials has an impact on learning in adults. The Cognitive Load Theory (Sweller, 1988) and the Multimedia Learning Theory (Mayer et al., 2001) posit that educational materials can be optimized for learning by considering cognitive demands of the learning setting. For example, when diagrams in science textbooks separate pictorial information from text, this may induce a *split-attention effect* whereby learners have to search the display and maintain relevant information in working memory. This design choice is argued to decrease learning by increasing extraneous cognitive load (according to the Cognitive Load Theory; Mayer & Moreno, 2003) and by impeding effective integration of presentation elements into a coherent mental representation (according to the Multimedia Learning Theory; Mayer, Heiser, & Lonn, 2001). Prior studies with adults have confirmed that spatial separation between images and text in educational materials affect learning gains (Jarodzka et al., 2015). For example, Beege and colleagues (2019) found a medium amount of spatial separation was optimal for balancing the costs of visual search of a display (when spatial separation between visuals and text is high) and the costs of visual crowding (when spatial separation is low between visuals and text).

However, findings of prior work with adult learners who are fluent readers and are *reading to learn* may have limited utility for the design of reading materials for young children who are not yet fluent readers and are *learning how to read*. A handful of studies explored the possibility that the ubiquitous practice of including illustrations in reading materials for beginning readers may interfere with the acquisition of reading skills. In these studies, researchers presented children with reading practice materials in which text was either accompanied by illustrations or presented in isolation (Braun, 1969; Samuels, 1967; Samuels, 1970; Torcasio and Sweller

In J. Culbertson, A. Perfors, H. Rabagliati & V. Ramenzoni (Eds.), *Proceedings of the 44th Annual Conference of the Cognitive Science Society.*

(2010). The results of these studies suggested that including illustrations and text in materials for beginning readers interfered with the acquisition of sight vocabulary and increased reading errors.

However, it is possible that the negative impact of illustrations on vocabulary learning and word decoding may be offset by the potential benefits of illustrations to *reading comprehension*. It has been suggested that including illustrations in books for beginning readers can help define the story setting and characters, thus contributing to text coherence and increasing motivation (Carney & Levin, 2002). Indeed, a recent study by Eng et al. (2021) showed that children vastly prefer reading a story with illustrations to the same story presented without illustrations. Furthermore, the design of illustrations in that study had an impact on children's attention to the text and reading comprehension. Researchers asked first and second grade students to read a beginning reader book. The commercially produced version of the book combined visuals that were relevant to the story with engaging but extraneous visuals that were not essential to understanding the story narrative. Researchers hypothesized that the presence of extraneous visuals may disrupt children's attention to text as children explore a visually appealing image and encode into memory details that are irrelevant to the story, thus reducing text coherence. Children's performance in this condition was compared with children's performance in a condition with all illustrations removed (which would help maintain attention to the text without competition from engaging visuals, but would not have illustrations contribute to defining the story setting) and a condition with extraneous visuals removed but relevant visuals retained (which could balance the costs of attentional competition between images and text, and the benefits of illustrations helping define the story setting). In line with the pre-registered hypothesis, gaze shifts away from text were highest in the commercially available version of the book and lowest in the condition in which all illustrations were removed. However, reading comprehension was highest in the condition in which only the illustrations *relevant* to the story were maintained. In other words, well-designed illustrations in a beginning reader book reduced gaze shifts away from the text compared to the commercially available version of the book (suggesting reduced attentional competition between text and illustrations) and increased reading comprehension compared to the condition in which the story was presented with no illustrations (suggesting that relevant illustrations can indeed contribute to text coherence).

The present study examines another common aspect of children's electronic book 'e-book' designs that combines engaging images and text in *close proximity* (see Figure 1-a). It is possible that this design choice amplifies attentional competition between illustrations and text, thus negatively impacting reading comprehension. When text and images compete for children's attention, frequent gaze shifts away from text could pose a challenge for maintaining the representation of information from text in working memory. To examine this possibility, the present study compares children's attention to the text and reading comprehension in a commercially available version of an e-book for beginning readers (with illustrations and text in close proximity) and a modified version of the e-book (which introduced spatial separation between illustrations and text). In line with the previous studies by Eng et al. (2020, 2021), this study utilized e-books as stimuli because children's earliest experiences with beginning reader books are now accessible in the form of e-books, especially with remote learning rising (Furenes, Kucirkova, & Bus, 2021).

Method

Participants

Data were collected from a sample of 49 first and and second grade children; however, only children who exhibited a minimum level of decoding proficiency on an independent measure of reading fluency (i.e., passed Level 1 on the Word Recognition in Isolation measure described below) continued with the study. Children who did not show the minimum level of reading proficiency read a simpler book with the experimenter as an alternative activity. The final sample consisted of 46 children ($Mage = 7.51$ years, $SD = .55$; 21 females, 23 males, and 2 children whose sex was not reported). Participants were recruited from schools around a mid-Atlantic city. The race and ethnicity information for the sample reported by the parents was as follows: 61% White, 20% Multiracial, 5% East Asian or Asian American, 4% African American or Black, 4% Other, 8% Unreported. Signed consent was obtained from the parents of each student. Participants were tested individually by research assistants naive to the hypothesis. The experimental protocol was approved by the University Institutional Review Board. Children were given a small prize for their participation.

Design and Procedure

The stimuli and study procedures utilized in the present study followed those of Eng et al. (2020, 2021).

Reading Material Stimuli The present study used a commercially available book titled *Good Job, Dennis* by Amy Kraft. This book is part of the *Hooked on Phonics Learn to Read* program, which helped ensure the ecological validity of study materials. Book design was manipulated within participants. Children read half of the book in the commercially available "Standard" Condition in which text is embedded within illustrations (high spatial proximity between text and illustrations) and the other half in the Partially separated "Partial" Condition (low spatial proximity between text and illustrations) where the text was moved to the right of the illustrations (see Figure 1 a-b). The

book had a total of 12 pages; children read 6 pages in each condition. Condition order (Standard first versus Partial first) was randomized and counterbalanced across participants to control for order effects. The size of illustrations and text remained the same across conditions. Minor modifications were made to the book to equate both halves of the book as closely as possible on the number of pages and the average number of words per page (1st half = 43.0 words, 2nd half = 42.3 words). The book was presented on a laptop computer with children reading aloud in a self-paced manner, using a button on the keyboard to advance to the next page. When children finished reading the story, the researcher assessed their reading comprehension (see the details below). Each testing session was videotaped with a Logitech C920 HD Pro Webcam.

Figure 1-a: Sample page of the Standard Condition with text close in proximity to illustrations.

Figure 1-b: Sample page of the Partial Condition with text spatially separated from illustrations.

Measure of Attention

Gaze Shifts Eye gaze is a common measure of attention and is particularly well-suited in the context of reading (Rayner, Ardoin, & Binder, 2013). This study used an SMI RED250 mobile eye tracker (SensoMotoric Instruments, Inc.) to measure children's eye movements while reading. We created three Areas Of Interest (AOI's) for text, illustrations, and white space; and then used SMI BeGaze Eyetracking Analysis Software to calculate gaze shifts away from text. We used the average number of gaze shifts per page as the outcome variable to quantify attentional competition.

Reading Comprehension Measure

Story Questions We used six open-ended comprehension questions adapted from the book publisher as the measure of reading comprehension. Asking open-ended recall questions about the characters, settings, story plot conflict and resolution from the narrative is one of the most common approaches to reading comprehension assessments with young children (Cain & Oakhill, 2006; Kendeou et al., 2009; Paris & Paris, 2003). There were three questions for each half of the book (two 2-point questions, and one 3-point question) for a total of 14 points. Questions were linked to content presented on specific pages, making it possible to clearly distinguish events from the first or second half of the book. For example, in the first half of the book the job of the main character, Dennis, is described; these story details are not part of the content in the second half of the book. Children were asked, "What is Dennis' job?" Children received full credit (2 points) if they identified that Dennis directs traffic and helps children cross the street, 1 point for a partial answer (e.g., *he helps children*), and 0 points if they failed to recall Dennis' job or provided an incorrect response. In the second half of the book, various animals escape from a pet shop including cats, dogs, birds, rabbits, and frogs; these story details are not part of the content in the first half of the book. Children were asked, "What animals get out of the pet shop?" Children received full credit (3 points) if they correctly identified all of the animals that escaped, 2 points if they identified at least 3 animals, 1 point if they identified only 2 animals, and 0 points if they failed to recall the animals that escaped or provided an incorrect response. Story comprehension was measured as the percentage of correct responses (out of 7 possible points per condition). Participants' responses to the story questions were scored twice by research assistants who were naive to the participants' condition assignment. Inter-rater reliability using Cohen's kappa (Cohen, 1960) was .85, indicating substantial coder consistency.

Reading Fluency Measure The Word Recognition in Isolation Test (WRI; Morris, 2013) was administered to children prior to reading the story and is an independent measure of reading fluency. The WRI measures the ability to recognize and decode words on lists that are graded in difficulty. While children read the book aloud, the experimenter also manually recorded the child's decoding accuracy for each word in the story using a running record (Clay, 1972) and the percentage of correct words read aloud was then calculated for each condition and in total.

Results

Reading Level

Children were beginning readers as evidenced by their performance on the WRI, the independent measure of children's reading proficiency ($M = 67.37$, $SD = 20.78$). The selected book was an appropriate difficulty level for independent reading based on children's mean performance on the Running Record ($M = 96.08\%$; $SD = 3.28\%$). The manipulation to the book condition did not influence children's decoding accuracy (Standard Condition Running Record: $M = 94.95\%$; $SD = 3.28\%$; Partial Condition Running Record: $M = 95.96\%$; $SD = 3.30\%$), $t(45) = 1.09$, $p = .28$; Cohen's d = 0.16.

Reading Comprehension

Children's comprehension scores were significantly higher in the Partial Condition ($M = 83.54\%$, $SD = 19.28\%$) than in the Standard Condition ($M = 62.11\%$, $SD = 20.91\%$), paired-sample $t(45) = 4.69$, 95% CI [12.23, 30.63] $p = .000025$; Cohen's $d = .69$. To assess possible order effects, we conducted a mixed analysis of variance (ANOVA) on reading comprehension, factoring order as the between-subject variable and book condition as the within-subject variable. There were no order effects ($F = 1.82$, $p = .169$). The results indicate that reading from the Partial Condition resulted in higher comprehension compared to reading from the Standard Condition, regardless of the quantity of words a child accurately read aloud and the order in which the storybook layout was presented (see Figure 2).

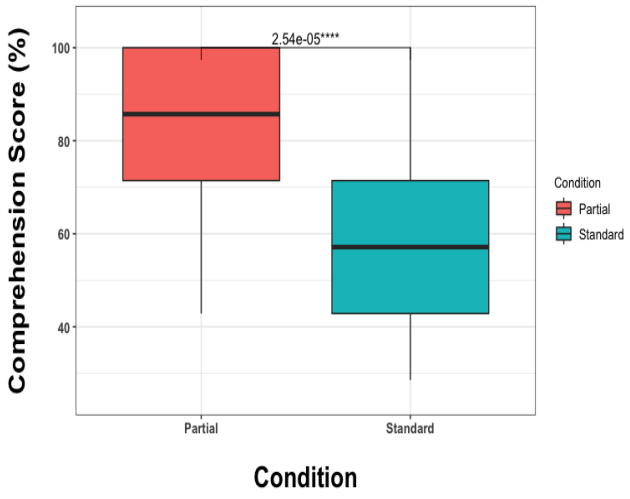

Figure 2: Percentage of correct answers on the story questions as a function of book layout; ****$p < .000025$.

Eye Tracking Results

Data from 1 child was not included in the analyses due to a tracking ratio <50%. There were no significant differences in average total reading time per page in the Standard Condition ($M = 78{,}625.25$ ms; $SD = 12{,}7045.15$ ms) compared to the Partial Condition ($M = 91{,}548.76$; $SD = 13{,}6053.73$ ms), paired-sample $t(44) = 1.04$, $p = .30$; Cohen's $d = .16$. Children who read from the Partial Condition on average shifted their gaze away from the text significantly less ($M = 12.32$, $SD = 10.33$) than children who read from the Standard Condition ($M = 18.65$, $SD = 14.87$), paired-sample $t(44) = 4.48$, $p = .000053$; Cohen's $d = .67$ (see Figure 3). To assess possible order effects, we conducted a mixed ANOVA on gaze shifts away from the text, factoring order as the between-subject variable and book condition as the within-subject variable. There were no order effects ($F = .14$, $p = .71$), indicating that reading from the Partial Condition resulted in lower gaze shifts away from the text compared to reading from the Standard Condition, regardless of the total reading time per page and the order in which the storybook layout was presented (see Figure 3 below).

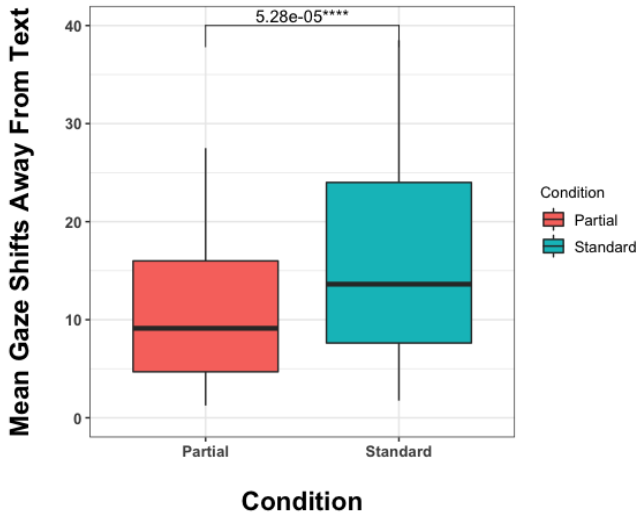

Figure 3: Average gaze shifts away from the text per page as a function of book layout; ****$p < .00006$.

The results validate the split-attention principle in children's storybooks: children's attention, indexed by their gaze shifts away from the text while reading, was negatively associated with reading comprehension in the Standard layout condition where text and illustrations were in close proximity. As shown in Figure 4, the more children's attention was split between the text and illustrations, the lower their reading comprehension scores were ($r = -.37$, $p = .011$). The Partial Condition may allow for more focused attention on the text by reducing attentional competition between text and illustrations.

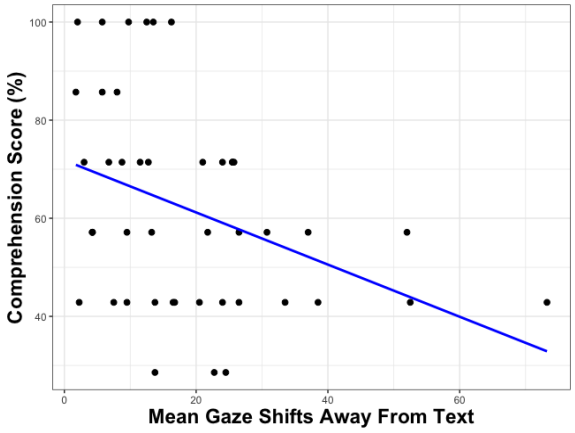

Figure 4: Scatterplot of negative association between gaze shifts away from the text and reading comprehension.

The Role of Individual Differences

Next, we examined whether the Partially separated condition might be especially beneficial for children who often shift their attention away from the text while reading. *Comprehension Gains*, or the difference score variable, was calculated by subtracting the Standard comprehension score from the Partial comprehension score for each child. Difference scores ranged from -42.86% to 71.43%, with a mean of 21.43% (*SD* = 28.57%). A score of 0 indicates a participant had the same score on the comprehension assessment in each condition. Children's gaze shifts were positively associated with their Comprehension Gains (r = .41, p = .005). Children who frequently shifted their gaze away from the text while reading had higher Comprehension Gains than children who looked away less (see Figure 5). Thus, the Partial condition was especially beneficial for children who look away from the text while reading and their comprehension scores improved the most from modifying the book layout.

Figure 5**:** Scatterplot of positive association between gaze shifts and comprehension gains.

Discussion

This study analyzed the effects of manipulating the spatial proximity between illustrations and text in books for beginning readers. Eng and colleagues (2020) provided the first systematic analysis of whether excluding extraneous details from illustrations for beginning readers could improve reading comprehension. Our study found similar benefits with a related manipulation to the book layout. It was found that children reading from the Partial Condition with increased spatial separation between text and illustrations achieved higher reading comprehension scores and looked away from the text significantly less compared to when children read from the book presented in the commercially-available Standard Condition with high spatial proximity between text and illustrations. These findings align with those of Eng et al. 2020, and the findings of current research on the design of educational materials for adults in which students learn best when their attention is not split between multiple sources of information (Ayres & Sweller, 2005; Beege et al., 2019).

We hypothesized that children who frequently shift their gaze while reading (i.e., less developed attentional control) would have greater gains in comprehension in the Partial Condition compared to children who do not frequently look away from the text while reading (i.e., children with more developed attentional control). Our findings supported this hypothesis: the Partial Condition was especially useful for children who were more easily distracted and who frequently shifted their gaze away from the text.

Frequent switching between two different tasks—reading the text to understand the story on one hand and exploring the engaging illustrations on the other hand—might place too much extraneous load on young children's working memory resulting in decreased story comprehension (Mayer & Moreno, 2003). Because text was not embedded within illustrations in the Partial Condition, this design may help children focus on the text and illustrations separately, as opposed to attempting to process both visuals and text simultaneously. Thus, increasing the spatial separation between illustrations and text for beginning readers may result in lower cognitive load than layouts with high proximity between illustrations and text which may increase the mental effort expended and decrease learning (Jarodzka, Janssen, Kirschner, & Erkens, 2015).

Segmenting the text and visuals may be beneficial to children who frequently look away from the text because these children's ability to selectively attend to text while suppressing surrounding illustrations in close proximity is less efficient. Researchers have found that children's attentional control and ability to focus are significant predictors of reading achievement when they enter formal education and continue to predict reading achievement until several years later in development (Guo, Connor, Tompkins, & Morrison, 2011; Markant, & Amso, 2021). Attentional control—a foundational component linked to school

readiness and reading achievement—should be taken into account when designing educational materials not only for fluent readers who are reading to learn, but also for beginning readers who are learning to read.

A limitation to this study is that future research is needed to determine the optimal text and illustration placement, and whether increasing the spatial proximity between text and illustrations too much may hinder learning by causing students to switch between text and illustrations more frequently as the distance between layout elements increases. Additionally, this study used a modest sample size; a larger number of participants in the future would allow us to further investigate developmental differences (e.g. differences across grade levels). If the findings of this study are replicated with other reading materials and across a broad range of students, this research can point to a cost-effective and easy to scale general principle for more optimal design of reading materials for beginning readers.

While other eye tracking outcome measures of pupil dilation that are commonly assessed in studies related to cognitive load–because children were tested in several schools–the lighting could not be controlled which is crucial for pupil dilation research. A direction we are currently pursuing is a more fine-grained analysis of the eye tracking data in whether the gaze shifts towards the illustrations are related to the text or not.

Subtle changes to the design of beginning reader books can improve both the experience as well as reading outcomes. The layout of text and illustrations are important to the educational potential for children learning-to-read, not just adults reading-to-learn. These findings highlight the importance of establishing a new industry standard, especially with the increasing use of e-books for learning in childhood (Furenes, Kucirkova, & Bus, 2021; Troseth & Strouse, 2017). In summary, this work highlights the importance of considering attentional control when designing books for beginning readers. This work in combination with the prior literature can help optimize the design of beginning reader books in which the layouts are created specifically to support–rather than hinder–learning.

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